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CANADA'S NON-FERROUS SMELTING/REFINING INDUSTRY
INCO THOMPSON TECHNOLOGICAL PROFILE

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Extraction Metallic

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ABSTRACT

Inco Thompson's present operations and their problems are briefly discussed, and a detailed evaluation is carried out on those smelter modernization alternatives which appear to offer a reasonable compromise between maximizing environmental benefit and productivity, and minimizing cost and technological risk.

It has been shown that only pyrrhotite rejection appears to be adequate to achieve the dual objectives of increasing competitiveness while significantly reducing SO_2 emissions.

The production of sulfuric acid to achieve SO_2 containment is not an attractive option, even if costs can be partly set-off by optimizing pyrrhotite rejection. This is primarily because the sale of sulfuric acid from a Thompson, Manitoba location is extremely unlikely to provide a positive netback to the smelter. An alternative sulfur fixation technology is required, which can either produce a higher value saleable product, or be implemented at much lower cost.

RÉSUMÉ

Le rapport donne un aperçu du fonctionnement actuel de la fonderie exploitée par Inco Thompson et des problèmes qui y sont reliés. Il présente également une évaluation détaillée des options relatives à la modernisation de la fonderie qui semblent offrir un compromis raisonnable entre la possibilité de tirer le maximum d'avantages en ce qui a trait aux conditions environnementales et à la productivité et celle de réduire au minimum les coûts et les risques inhérents à la technologie.

On a démontré que seul le procédé du rejet de la pyrrhotine semble répondre au double objectif, à savoir, l'accroissement de la capacité concurrentielle tout en réduisant de façon substantielle les émissions de SO_2.

La production d'acide sulfurique dans le but d'éliminer les émissions de SO_2 n'est pas une option intéressante bien que l'optimisation du procédé de rejet de la pyrrhotine puisse compenser en partie le coût des travaux. Ceci découle principalement du fait qu'il est fort peu probable que la vente d'acide sulfurique, à partir de la localité de Thompson au Manitoba, procure un revenu net à la fonderie. Une autre technique de fixation de soufre plus rentable qui permettrait de fabriquer un produit ayant une valeur marchande supérieure à un coût moindre est nécessaire.

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1. INTRODUCTION

This report is one in a series of reports which will attempt to assess the competitiveness of Canada's non-ferrous smelting industry and recommend strategies for improving the industry's competitive position, while simultaneously providing acceptable methods for reducing SO_2 emissions. The report provides the following information:

- A brief description of Inco Thompson's present and projected future operations and their problems.

- A brief description of the proposed modernization alternatives and their advantages and disadvantages.

- An outline of the methodology used for comparing the modernization alternatives to the present operations (base case).

- An assessment of the impact of the modernization alternatives on capital and operating costs and smelter/refinery outputs, revenues and SO_2 emissions.

- An evaluation of the proposed alternatives and recommendations on future R&D initiatives which could be considered to improve the economics of SO_2 containment at Thompson.

2. PRESENT OPERATIONS

Inco's Thompson, Manitoba Division is one of the world's largest fully integrated nickel mining, milling, smelting and refining complexes. The main Thompson ore body was discovered in 1956 following many years of geological exploration in the mineralized area 640 km north of Winnipeg. Construction of the townsite and operating facilities began in 1957. Refined nickel production started in March 1961 after an expenditure of $25 million for exploration and $140 million for mining and processing plants.

The original plant had a nominal mining/milling capacity of approximately 6,600 tons ore per day and electric smelting capacity for 2,200 tons concentrate per day. Electrolytic refinery capacity was nominally 75 million lb nickel per year. In 1968, mill capacity was increased to a nominal 18,000 tons ore per day and smelter capacity was increased to a nominal 3,500 tons concentrate per day. Electrolytic refinery capacity was increased to about 100 million lb nickel per year. Mining and processing capital expenditures between 1961 and 1971 amounted to $270 million.

Power for the townsite and the plants is supplied by Manitoba Hydro's Kelsey generating station located on the Nelson River, 85 km from Thompson.

2.1 Mining and Milling

Inco currently operates the Thompson underground mine, which is located at the smelter complex, and the Pipe open pit mine, located approximately 30 km to the south. The Birchtree underground mine, 5 km from Thompson, was in production from 1969 to 1977, and is presently maintained in standby condition.

The principal minerals in the Thompson area ores are pentlandite containing 34% nickel, nickeliferous pyrrhotite containing up to 1% nickel, and small amounts of chalcopyrite containing 35% copper. Cobalt is associated with the nickel in a ratio of approximately 1/50. The ores also contain minor amounts of precious metals, but these are of much less economic importance than in the case of Inco's Sudbury area ores.

Thompson ore, (typically 2.8% Ni and 12% S) is crushed underground to minus 6". In the mill the ore is further crushed to minus one inch and then wet ground in rod and ball mill circuits to approximately 80% minus 65 mesh. The ground pulp, at approximately 40% solids is treated by froth flotatation to yield pentlandite concentrate (28% Ni), which is sold to Sherritt Gordon, a nickel concentrate (6% Ni, 0.3% Cu) and a copper concentrate containing up to 20% Cu, and 3% Ni.

The Pipe ore, (0.9% Ni and 5% S) is crushed at the pit to minus 7", ard delivered to a separate crushing, grinding and flotation circuit at the Thompson mill. The ore contains large proportions of talcose gangue minerals, and must be ground to a finer consistency and floated at a relatively low (20% solids) pulp density to achieve satisfactory mineral separation. The Pipe ore circuit yields only one concentrate (10% Ni, 0.6% Cu) which is combined with Thompson nickel concentrate for smelting. The Pipe ore accounts for about 22% of total nickel production.(1)

It should be noted that the overall ore to concentrate ratio for Thompson ore is about 3.0/1, nickel recovery is about 95%, and 28% of the sulfur in ore is rejected to tailings. The ore to concentrate ratio for the Pipe ore is about 15/1, nickel recovery is about 79% and 72% of the sulfur in ore is rejected to tailings. For the combined operations overall sulfur rejection to tailings is about 43%, and nickel recovery is about 91%. (1)

The differences in metal recoveries and concentration ratios for the two ores are primarily a reflection of the different ore mineralogies and milling characteristics.

2.2 Smelting and Refining

The Thompson smelter flowsheet is shown in Figure I.

The original smelter included three fluid bed roasters, each directly coupled to an 18 MVA electric furnace, four Pierce Smith converters, two matte holding furnaces and casting facilities for producing matte anodes. In 1968 smelting capacity was increased by the addition of two larger fluid bed roasters, each coupled to a 30 MVA electric furnace. Also located in the smelter building are dewatering facilities (thickeners and filters) for mill concentrates and reverts from the nickel refinery.

In the roasters about 50% of the sulfur in the nickel concentrate is removed as a relatively high strength (10% SO_2) gas. The roaster calcine with appropriate flux additions, is then smelted in the electric furnaces to produce a 25% Ni matte and a discard slag. The matte is further oxidized and fluxed in the batch converters to produce a 75% Ni matte, which is cast into anodes for refining. Converter slag is recycled to the electric furnaces. All SO_2 bearing off-gases from the roasters, electric furnaces and converters are cleaned and discharged to atmosphere from the smelter stack.

The refinery flowsheet is shown in Figure 2.

Matte anodes are corroded in sulfate/chloride electrolyte and pure nickel cathodes are plated in compartments containing purified catholyte. Full size cathodes are sheared, either at Thompson or at Port Colborne, to sizes to suit customer requirements. Spent anodes are washed to separate the slimes and are then crushed and ground for

use in the nickel leach/purification circuit. The main steps in electrolyte purification comprise copper removal using hydrogen sulfide, nickel replenishment in the leach, and removal of cobalt plus iron using chlorine and soda ash.

Refinery products comprise regular electronickel, AP electronickel (sulfur depolarized for electro-plating) and cobalt oxide. By-products (or "reverts") include sulfide anode slimes (approximately 95% elemental sulfur), copper residue and unleached matte, all of which are recycled to the smelter.

It is now normal practice to treat these refinery residues, along with the mill copper concentrate, in one of the small roaster/electric furnace/converter circuits, to produce a high copper bessemer matte (30% Cu, 48% Ni), suitable for direct processing in Inco Sudbury's matte processing plant. This matte is the main bleed stream for the recovery of copper and precious metals from Inco's Manitoba division.

A more detailed description of Inco Thompson's smelter and refinery can be found in references 2, 3 and 4.

3. PROJECTED FUTURE OPERATIONS & PROBLEMS

The Pipe ore is approaching depletion and the mine will be shut down by the end of 1985. Nickel production rates will be maintained at required levels using stockpiled Pipe ore, prior to initiating open pit mining of the new Thompson ore body, which is scheduled to commence early in 1986.

For the purpose of this study it is assumed that Thompson open pit ore will be of the same composition as underground ore. This assumption may be slightly inaccurate for early years of pit operation but will be valid for later years. Because of the lower percentage of sulfur rejected to tailings, replacement of the Pipe ore with Thompson open pit ore, without improved metallurgy in the mill, will result in an increase in smelter SO_2 emissions of about 8%. It is very important therefore that improved methods be implemented to increase sulfur rejection from Thompson ore, while optimizing nickel and by-product metal recoveries. To accomplish this, more efficient methods for separating pyrrhotite from pentlandite will have to be developed.

The Thompson smelter constitutes a relatively modern and efficient processing operation. The most serious problem is the containment of SO_2 emissions, all of which are presently being vented to atmosphere.

The SO_2 from the fluid bed roasters (about 50% of total SO_2) is in the form of a relatively high strength gas which could be efficiently captured in an acid plant. Electric furnace gases however (20% of total SO_2) are too dilute for capture in an acid plant, while converter gases (30%) are intermittent, variable strength and costly to capture, due to the batch nature of the process.

Regardless of the technical feasibility of producing acid from the various SO_2 gas streams, the question of what to do with the acid afterwards, remains a very serious problem. Studies indicate that marketing acid from a Thompson location, or disposing of it on site as gypsum, will result in a negative netback to the smelter of about $50/tonne of acid. To improve the economics of SO_2 capture at Thompson an alternate sulfur fixation technology is required, which can either produce a higher value saleable product, or be implemented at much lower cost.

The electrolytic nickel refinery employs efficient technology which, especially in Thompson's circumstances, has distinct advantages over conventional metallic nickel anode electrolysis. It is possible, however, that a matte leach/electrowin process could be a simpler and more economic alternative to the existing process, and could also improve by-product recovery and value, and reduce SO_2 emissions by recovering an elemental sulfur by-product.

If expansion of refinery capacity is needed to handle future smelter output, it may be desirable to investigate this alternate technology for nickel refining.

4. PROPOSED MODERNIZATION ALTERNATIVES

The following modernization alternatives were selected, based primarily on their relatively short term technical feasibility, and on maintaining a reasonable compromise between maximizing environmental benefit and productivity, while minimizing cost and technological risk.

4.1 Mill Modernization

Implementation of an improved pyrrhotite rejection (PR) process is potentially the most economically attractive alternative for reducing SO_2 emissions at Thompson by at least 30%. Since 1975, Inco Thompson staff have achieved significant reductions in emissions, by increasing the rejection of pyrrhotite to tailings. Improvements in mill flotation separation have been achieved and the utilization of magentic separators, salvaged from Ontario Division's Iron Ore Recovery Plant, has contributed to improved results. However, the PR process has not yet been optimized for Thompson ore. To maximize the economic and environmental benefits it is essential that the process

be optimized to ensure that savings in smelter operating costs (resulting from the higher grade concentrate) can more than offset the additional mining/milling costs resulting from lower metal recoveries from the ore. To accomplish this, considerable development work will be required to determine the best combination of flotation and magnetic separation techniques for maximizing concentrate grade while minimizing metal losses to tailings.

4.2 Smelter Modernization

Two SO_2 capture options were evaluated, in combination with pyrrhotite rejection; one to produce sulfuric acid from roaster gases only, and the other to produce acid from roaster and converter gases, using conventional acid plant technology in both cases.

In addition, Inco's RRS process[5] was also evaluated for application at Thompson for comparative purposes.

4.2.1 Produce Sulfuric Acid from Roaster Gases

To implement this option, roaster gases from the smelter nickel and copper-nickel circuits would be directed, via new high velocity flues and new electrostatic precipitators, to a new single absorption acid plant.

All of the roaster gases would be delivered to the acid plant. The gases would be cooled by a combination of water spray evaporation and air dilution. SO_2 concentration in feed to the acid plant converter would be maintained at 7.5% or better. The acid plant would utilize standard Monsanto technology and achieve an average conversion efficiency of 96%.

This option has the potential to reduce smelter SO_2 emissions by about 50 to 60%.

4.2.2 **Produce Sulfuric Acid from Roaster and Converter Gases**

To implement this option roaster gases would be captured and cooled as in 4.2.1.

Converter gases would be captured utilizing new tight fitting primary hoods, with secondary hoods for work place environment control. Fumes from the secondary hoods would be vented to the smelter stack. Gases from the primary hoods would be directed, via new high velocity flues and new electrostatic precipitators, to a common flue feeding roaster and converter gases to a single absorption acid plant.

About 80% of the Pierce-Smith converter gases would probably be captured in the primary hood, but the acid plant would be sized to process 100% of the roaster and converter gases. Converter gas dilution would be controlled to maintain not less than 3% SO_2 in the gases exiting the electrostatic precipitator. The combined roaster and converter gases would be maintained at not less than 4.5% SO_2 at the entry to the acid plant converter. The acid plant would utilize standard Monsanto technology and achieve a 96% average conversion efficiency. This option has the potential to reduce smelter SO_2 emission by about 80 to 90%.

4.2.3 **Implement Roast Reduction Smelt (RRS) Process**

The RRS process[5,6] has been extensively developed by Inco for potential application at Copper Cliff. Implementation at Thompson would require the following:

- The two existing 18 ft. diameter fluid bed roasters would be replaced by two taller 21 ft. diameter units. New primary cyclones would be required together with new high velocity flues, new electrostatic precipitators and a new slurry feeding system.

- the crucibles and most of the steel supports for the two 30 MVA electric furnaces would be completely rebuilt. Copper cooling fingers would be required, as well as afterburners for the furnace gases. A coke receiving and distribution system would have to be installed.

- The converter flux feed systems would be upgraded to provide a higher degree of control of fluxing rates.

- Roaster gases would be directed to a new acid plant, as described in Section 4.2.1.

This option has the potential to reduce smelter SO_2 emissions by about 80 to 87%.

5. METHODOLOGY FOR COMPARISON OF MODERNIZATION ALTERNATIVES

The metallurgical balances and capital and operating costs documented in this report are based primarily on the M. Head report,[1] and on discussions with Inco personnel. All material balances are based on a constant nickel output of 50,000 tonnes/year (mty).

5.1 Mill Throughputs & Recoveries

Mill throughputs, grades and recoveries for the base case and process modernization options are shown in Table 1.

In all cases it is assumed that the Thompson open pit mine is in operation and that the ore is the same as the Thompson underground mine. Throughputs for the RRS process (versus existing process) are

also shown, since ore requirements are slightly lower due to a slightly higher nickel recovery in the RRS process.

The effect of pyrrhotite (Po) rejection on throughputs and recoveries is based on Inco Thompson estimates of mill performance to reject 50% of the input sulfur to tailings. To achieve this level of sulfur rejection it is estimated that nickel recoveries would decrease from 95.4% to 91.6%, while copper and cobalt recoveries would decrease from 96.5% to 93.6% and 83.5 to 78.9% respectively. Both nickel and copper concentrates would continue to be produced. Average concentrate grade would increase to 14% from 8% nickel, and overall ore to concentrate ratio would increase to about 5.5:1 from 3:1. About 95% of total recovered nickel would be in the nickel concentrate, while about 75% of total recovered copper would be in the copper concentrate. At least 95% of recovered cobalt would be in the nickel concentrate.

Po rejection would also decrease the recovery of silver and PM's (platinum group metals and gold). This decrease in recovery has been assumed to be the same as that for nickel, so that throughputs of silver and PM's in concentrates are the same for Po rejection as for the base case. This equates to a decrease in recovery of about 2.5% to 3% (73.0 to 70.5% for silver, and 71 to 68% for PM's).

Although "optimum" Po rejection is defined in this study as achieving 50% rejection of sulfur to tailings, this may in fact not be optimum. Higher levels of Po rejection may be possible, if on-going testwork to improve the efficiency of pyrrhotite separation from pentlandite proves successful, and if savings in smelter costs can more than off-set increased mining/milling costs resulting from lower nickel recovery.

5.2 Smelter Throughputs & Recoveries

Smelter throughputs, grades and recoveries for the base case and modernization options are shown in Table 2. Sulfur balances for the process and sulfur capture options are shown in Table 3. Material balances are based on the following assumptions:

1) Po rejection results in a small increase in nickel and copper recovery in the smelter, and a significant increase in cobalt recovery. The recovery increases are from 96.5 to 97.2% for nickel; 92.4 to 94.1% for copper and 51.1 to 61.6% for cobalt.

2) The RRS process results in a further increase in recovery for nickel and cobalt to 97.6% and 70.6% respectively, but a decrease in copper recovery to 90.3%.

3) The recovery of silver and PM's in the smelter is assumed to be constant at 95% for all options.

4) All concentrates produced in the mill will be processed through the Thompson smelter. This may not be a valid assumption, since about 14,000 mty Ni in concentrate is presently shipped to Sherritt Gordon, and Thompson refinery capacity is only about 41,000 mty Ni.

5) For the RRS process, SO_2 capture and sulfuric acid production are based on 87% sulfur removal as SO_2 in the roasters. This is an optimistic figure and could actually be 80% or less.

6) For the existing process, SO_2 capture and sulfuric acid production are based on very conservative estimates of sulfur removal in the roasters ($<50\%$). In fact 55 to 60% sulfur removal can be achieved, so that SO_2 capture and sulfuric acid production could be up to 20% higher than the figures quoted in Table 3 for the two SO_2 capture options.

7) All of the sulfur in nickel matte going to the refinery is assumed to be recycled to the smelter in the form of "reverts" which will include elemental sulfur.

8) Sulfuric acid production is based on 96% conversion efficiency in the acid plant for all SO_2 capture options.

9) For the purpose of calculating revenues, a product breakdown for the base case and modernization options is shown in Table 4, and

includes sulfuric acid production. The figures assume no metal losses in the refinery. All by-products, with the exception of cobalt, are recovered in the form of copper/nickel matte, which is sent to Ontario Division for further processing. Approximately 11.5% of total nickel production is contained in this matte, and this percentage is not expected to change significantly with the processing options. Cobalt is recovered at Thompson as a saleable oxide.

5.3 Capital Costs

A breakdown of the capital costs for the mill and smelter moernization options is shown in Table 5. Capital costs for the mill modernization are based on Inco estimates to achieve sulfur rejection levels greater than 50%, with a possible target objective of 60%.

Smelter capital costs are based primarily on the Head report,[1] while acid plant capital costs are also based on this report and on CANMET in-house data. Acid plant design capacity is based on 320 operating days per year.

All capital costs are in 1983 Canadian dollars and are considered accurate to $^{+}$ 30%.

5.4 Operating Costs

A breakdown of incremental operating costs for the modernization options is shown in Table 6. Mining and milling incremental costs for Po rejection are based on recent Inco Thompson unit costs per tonne of ore. It is also assumed that 54% of production will come from the Thompson underground mine.

Incremental smelter costs are based on Inco data and the M. Head report.(1) Acid plant operating costs are derived from CANMET in-house data and previous studies.(6,7,8,9) Refining costs are assumed to remain the same for all options. All costs are in 1984 Canadian dollars.

Incremental costs do not include corporate overhead, interest charges or depreciation. Incremental costs for the Po rejection process are also not included because they are not known at this time.

5.5 Revenues

Incremental throughputs and revenues for the modernization options are shown in Table 7. Prices used are based on EMR and DRIE

commodity forecasts for the 1990's. All prices are in 1982 US dollars and reflect deductions for refining charges of 25% for copper, 44% for cobalt and 5% each for silver and PM's. Acid netbacks are based on shipping to a Chicago area market.

6. IMPACTS OF MODERNIZATION

The impacts of modernization are summarized in Table 8, which shows incremental outputs, revenues and operating costs for each modernization option, along with total capital costs and SO_2 emissions. All incremental figures are relative to the base case. It should be emphasized however that the "base case" is essentially equivalent to Inco's 1980 plant operations, but with the Thompson open pit replacing the Pipe ore, and resulting in an average sulfur rejection to tailings of only 28% of sulfur in ore. The incremental operating costs, revenues and SO_2 emissions attributed to optimum Po rejection are therefore related to this hypothetical mode of operation, rather than to present day operations, where Pipe ore is still being processed, and sulfur rejection to tailings is already approaching 50%, as a result of continued improvements in plant operation.

The figures indicate that only improved pyrrhotite rejection would provide a total operating surplus to pay for the capital investment involved. This incremental benefit is estimated at about $C4 million/yr, about 75% of which is due to reduced operating costs in the smelter, and the remaining 25% to increased by-product revenues

resulting from higher ore requirements to maintain constant nickel output. Based on a capital cost estimate of $C6 million, capital write-off for this option could be less than two years. SO_2 emissions would be reduced by about 90,000 tpy or about 29% less than what would be expected if the Thompson open pit was put into production without implementing the improved pyrrhotite rejection technology.

Capture of SO_2 from the roasters would reduce SO_2 emissions by an additional 105,000 tpy to bring total SO_2 capture to about 62%. Additional capital costs for this option would be about $C47 million. Although a small operating cost saving of about $C1 million/yr (resulting from pyrrhotite rejection) is possible, this would be more than off-set by the negative netback from acid sales (estimated at nearly $C8 million/yr) resulting in an overall operating deficit of about $C5.8 million/yr.

Capture of SO_2 from roasters and converters would reduce SO_2 emissions by an additional 173,000 tpy and bring total SO_2 capture to about 84%. Additional capital costs would be about $C95 million and operating costs would increase by about $C1 million/yr. Total operating deficit would be about $C13 million/yr, nearly all of which would be due to negative netbacks on acid.

For the RRS option, additional capital costs would approach $C126 million and operating deficit would be about $C20 million/yr, about 76% of which would be due to negative acid netbacks. SO_2

emissions would be reduced by about 195,000 tpy, to bring total SO_2 capture to about 91%. Although higher nickel and cobalt recoveries may be possible with the RRS process, the potential for increased metal revenues is not great enough to off-set the increased operating costs and make this option look attractive, even if negative acid netbacks are neglected.

7. EVALUATION OF MODERNIZATION ALTERNATIVES

It is obvious from the analyses that the production of sulfuric acid at Thompson to achieve SO_2 containment is not an attractive option, even if acid netbacks are zero and if costs can be partly off-set by optimizing pyrrhotite rejection. It has also been shown[10] that fertilizer production and/or other SO_2 capture and disposal options, using limestone or regenerative scrubbing systems, will be equally unattractive.

It is desirable therefore to minimize SO_2 emissions by first optimizing the Po rejection process. It may then be possible to consider longer term initiatives to produce elemental sulfur, either by reduction of SO_2 with a relatively low cost reductant (coal or tar sands coke), or by introducing new or modified refining techniques to handle lower grade nickel matte and produce H_2S or elemental sulfur directly in the refining process. This elemental sulfur could be recovered and stored with no detrimental environmental effects, or sold if a positive netback to the smelter can be obtained.

The probable costs of producing elemental sulfur from SO_2 by reduction with a low cost carbonaceous reductant have already been estimated.[10] It would appear that sulfur prices would have to at least double before this option could be considered attractive enough to warrant further investigation. Even if the carbonaceous reductant could be obtained free of charge, the sale of sulfur from a Thompson location at present day prices would still not pay for sulfur production costs. It would be very difficult therefore to justify any R&D effort on this approach, unless there is some real reason to believe that sulfur prices in the future will increase substantially. Based on the availability of other sources of SO_2 for making sulfuric acid, this does not appear likely. It is recommended therefore that technology development initiatives for increasing SO_2 containment at Thompson be confined to the milling and refining operations.

8. RECOMMENDED TECHNOLOGY DEVELOPMENT INITIATIVES

8.1 Milling

The downstream economic and environmental benefits associated with the pyrrhotite rejection process have already been estimated. To maximize these benefits, a comprehensive R&D program will be required, incorporating both small scale and pilot scale studies, to develop the best combination of flotation and magnetic separation techniques which will minimize metal losses during pyrrhotite rejection while maximizing the grade of nickel concentrate and the nickel/sulfur ratio.

8.2 Refining

Presently about 8% of total input sulfur in concentrates is converted to elemental sulfur in the nickel refinery, and is subsequently recycled to the smelter and removed as SO_2. The objectives of R&D initiatives would be to dramatically increase this percentage conversion to elemental sulfur in the refining process, and to recover the sulfur, rather than recycle it to the smelter. To accomplish this the amount of sulfur removed as SO_2 in the smelter would of course have to be decreased, probably by reducing or eliminating the converter operations. The refining process would also have to be modified to handle a lower grade matte. This could be accomplished by utilizing a matte leach process which would produce H_2S for subsequent conversion to elemental sulfur in a claus type reactor, or by ferric, cupric, or electrolytic leach methods which would produce elemental sulfur directly. In all cases nickel would have to be recovered by electrolytic techniques. An extensive R&D program would be required to resolve the major technical problems associated with this approach, and to assess the economic and environmental incentives to pursue it. It is recommended therefore that these alternatives be investigated and evaluated, to determine the potential for improving both SO_2 containment and smelter/refinery operating costs at Thompson.

9. ACKNOWLEDGEMENTS

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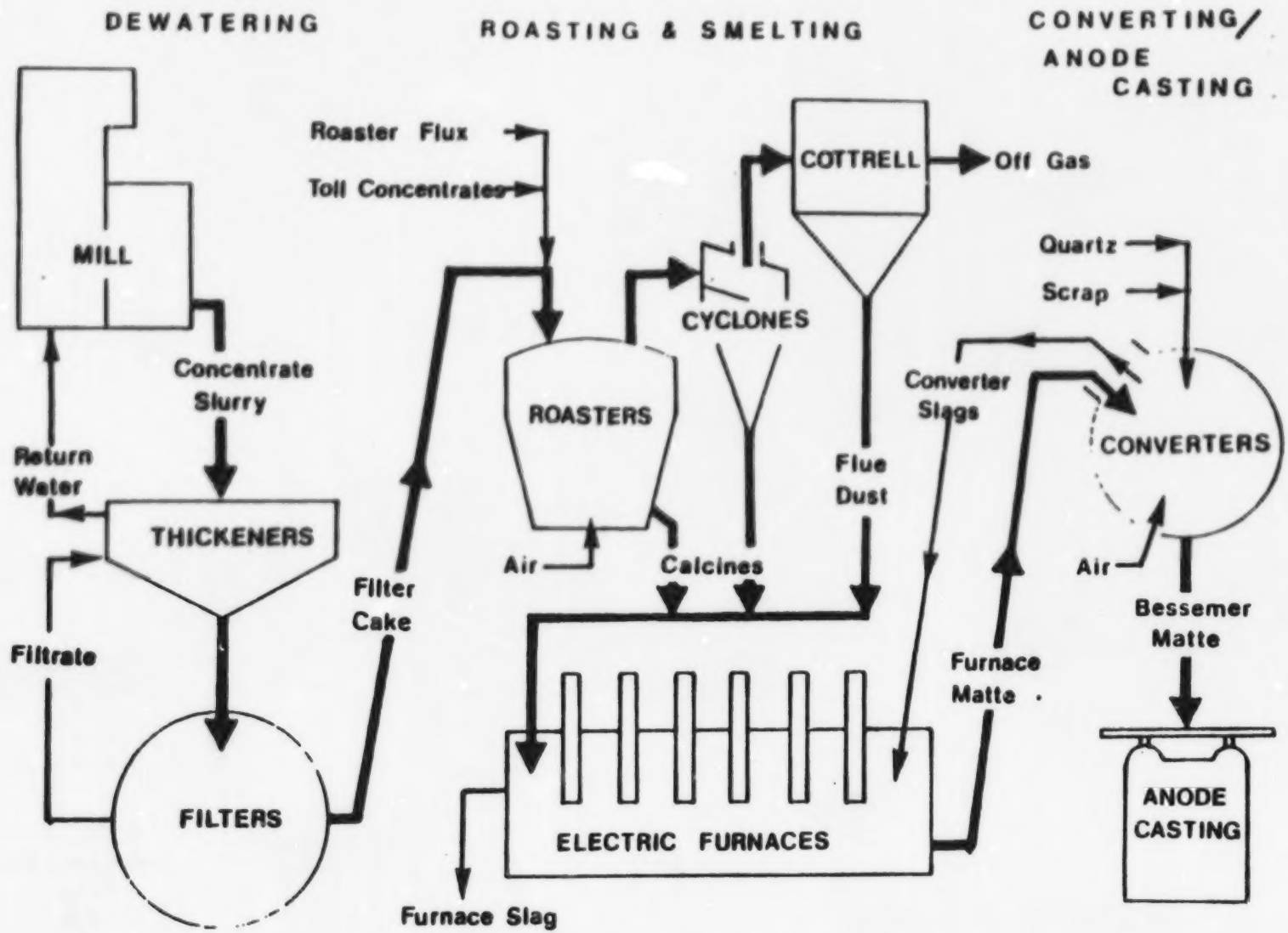
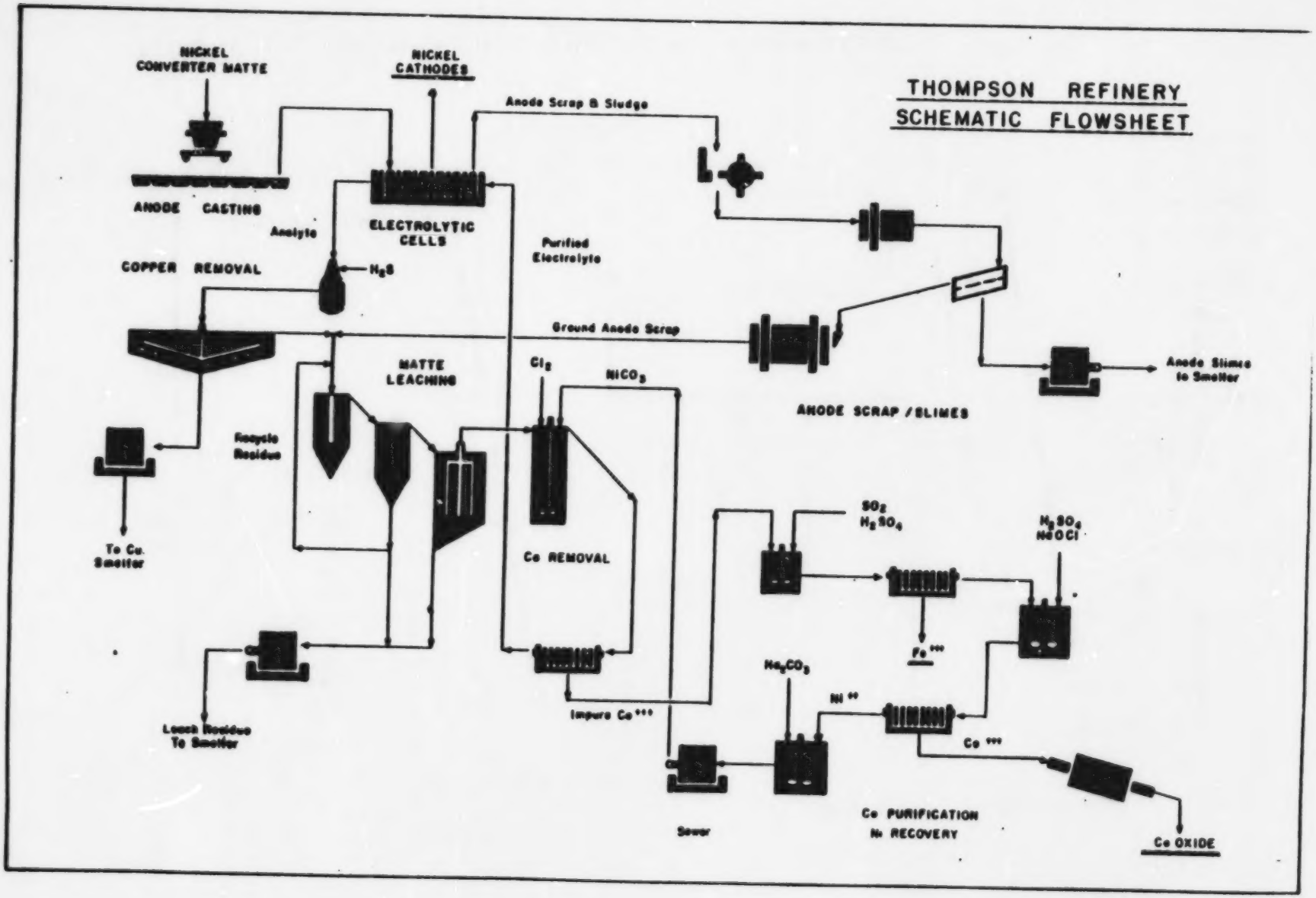


FIGURE 1 THOMPSON SMELTER FLOWSHEET

FIGURE 2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SCHEMATIC FLOWSHEET
NICKEL CONVERTER MATTE
NICKEL CATHODES
Anode Scrap & Sludge
ANODE CASTING
ELECTROLYTIC CELLS
Anolyte
Purified Electrolyte
COPPER REMOVAL
H_2S
Ground Anode Scrap
MATTE LEACHING
Cl_2
$NiCO_3$
ANODE SCRAP / SLIMES
Anode Slimes to Smelter
Recycle Residue
To Cu. Smelter
Co REMOVAL
SO_2
H_2SO_4
H_2SO_4
NaOCl
Fe^{+++}
Na_2CO_3
Ni^{++}
Co^{+++}
Impure Co^{+++}
Leach Residue To Smelter
Sewer
Co PURIFICATION
Ni RECOVERY
Co OXIDE

TABLE 1 INCO THOMPSON

MILL THROUGHPUTS, GRADES AND RECOVERIES

For Base Case, and Process Options

Basis: 50,000 mty Ni output

MILL INPUTS & OUTPUTS		METAL THROUGHPUTS mty or oz/y x 10^3						METAL GRADE % or oz/mt						MILL RECOVERIES %					
Type	mty x 1000	Ni	Cu	Co	Ag	PM's	S	Ni	Cu	Co	Ag	PM's	S	Ni	Cu	Co	Ag	PM's	S
Base Case																			
Ore	1,947	54.31	4.03	1.05	389.4	17.1	231.7	2.79	0.207	0.054	0.2	0.009	11.9	100	100	100	100	100	100
Tailings	1,299	2.52	0.14	2.17			64.4	0.194	0.011	0.013			4.97	4.63	3.51	16.5			27.9
Ni Concentrate	631	51.20	1.58	0.87			162.9	8.11	0.25	0.137			25.8	94.27	39.19	82.1			70.3
Cu Concentrate	17	0.60	2.31	0.01			4.2	3.53	13.6	0.059			24.7	1.10	57.30	1.4			1.8
Total Concentrate	648	51.80	3.89	0.88	284	12.1	167.1	7.99	0.60	0.136	0.438	0.019	25.8	95.37	96.49	83.5	73	71	72.1
Optimum P^{80} Rejection (Existing Process)																			
Ore	2,013	56.16	4.17	1.09	402.6	17.7	239.5	2.79	0.207	0.054	0.2	0.009	11.9	100	100	100	100	100	100
Tailings	1,646	4.71	0.27	0.23			119.7	0.286	0.016	0.014			7.27	8.39	6.39	21.1			50.0
Ni Concentrate	273	48.63	0.98	0.81			91.5	17.82	0.359	0.297			33.5	86.59	23.61	74.6			38.2
Cu Concentrate	94.7	2.82	2.92	0.05			28.2	2.98	3.08	0.053			29.8	5.02	70.0	4.3			11.8
Total Concentrate	367.7	51.45	3.90	0.86	284	12.1	119.8	13.99	1.06	0.234	0.77	0.033	32.6	91.61	93.61	78.9	70.5	68	50.0
Optimum P^{80} Rejection (RRS Process)																			
Ore	2,003	55.89	4.15	1.08	400.6	17.6	238.4	2.79	0.207	0.054	0.2	0.009	11.9	100	100	100	100	100	100
Tailings	1,640	4.69	0.26	0.23			119.1	0.286	0.016	0.014			7.27	8.39	6.39	21.1			50.0
Ni Concentrate	272	48.4	0.98	0.81			91.1	17.82	0.359	0.297			33.5	86.59	23.61	74.6			38.2
Cu Concentrate	94.2	2.8	2.90	0.05			28.1	2.98	3.08	0.053			29.8	5.02	70.0	4.3			11.8
Total Concentrate	366	51.20	3.88	0.85	283	12.0	119.2	13.99	1.06	0.234	0.77	0.033	32.6	91.61	93.61	78.9	70.5	68	50.0

TABLE 2 INCO THOMPSON

SMELTER THROUGHPUTS, GRADES AND RECOVERIES

For Base Case and Process Options

Basis: 50,000 mty Ni Output

OPTIONS	MATERIAL FLOWS	CONCENTRATE FEED		SMELTER OUTPUTS					RECOVERIES (%)		
				Matte		Electro-nickel	Co Products	Total Products			
		10^3 mty or oz/y	Grade % or oz/mt	10^3 mty or oz/y	Grade (%)	10^3 mty	10^3 mty	10^3 mty or oz/y	Ore to Conc.	Conc. to Metal	Or to Met.
BASE CASE	Concentrate	648									
	Ni	51.80	7.99	5.75	47.7	44.25		50.00	95.37	96.53	92.(
	Cu	3.89	0.60	3.60	29.8			3.60	96.49	92.44	89..
	Co	0.88	0.136	0.06	0.5		0.39	0.45	83.50	51.1	42..
	Ag	284	0.438	270				270	73	95	69.(
	PM's	12.1	0.019	11.5				11.5	71	95	67.'
OPTIMUM pO REJECTION (Existing Process)	Concentrate	367.7									
	Ni	51.45	13.99	5.84	47.7	44.15		50.00	91.61	97.19	89.(
	Cu	3.90	1.06	3.67	29.8			3.67	93.61	94.11	88.1
	Co	0.86	0.233	0.06	0.5		0.47	0.53	78.90	61.6	48.(
	Ag	284	0.77	270	270			270	70.5	95	67.(
	PM's	12.1	0.15	11.5	11.5			11.5	68	95	64.(
OPTIMUM pO REJECTION (RRS PROCESS)	Concentrate	366									
	Ni	51.20	13.99	5.58	47.7	44.42		50.00	91.61	97.65	89.(
	Cu	3.88	1.06	3.50	29.8			3.50	93.61	90.27	84.'
	Co	0.85	0.233	0.06	0.6		0.54	0.60	78.90	70.6	55.7
	Ag	283	0.777	269				269	70.5	95	67.(
	PM's	12.0	0.15	11.4				11.4	68	95	64.(

TABLE 3 INCO THOMPSON **SMELTER SULFUR DISTRIBUTION FOR VARIOUS PROCESS AND SO_2 CAPTURE OPTIONS**

Basis: 50,000 mty Ni Output

SULFUR DISTRIBUTIONS	BASE CASE (Existing Process) (No Improved Po Rejection)		OPTIMUM P^O REJECTION							
			Existing Process						RRS Process	
	mty x 10^3									
S in Concentrates	167.1		119.8						119.2	
S in SO_2 from										
- Roasters	80.1		54.1						104.2	
- Converters	45.8		45.0						4.8	
- Furnaces	30.9		12.8						5.5	
Total S in SO_2 Off-Gases	156.8		111.9						114.5	
SO_2 CAPTURE OPTION	No SO_2 Capture		No SO_2 Capture		Roaster Only		Roaster & Converter		Roaster Only	
S Fixed as H_2SO_4	-		-		51.9		86.7		100	
S in SO_2 Emissions										
- Roasters	80.1		54.1		-		-		-	
- Converters	45.8		45.0		45.0		8.8		4.8	
- Furnaces	30.9		12.8		12.8		12.7		5.5	
- Acid Plant	-		-		2.2		3.7		4.2	
Total S in SO_2 Emissions	156.8		111.9		60.0		25.2		14.5	
S Distribution %	Conc. to Metal	Ore to Metal	Conc. to Metal	Ore to Metal	Conc. to Metal	Ore to Metal	Conc. to Metal	Ore to Metal	Conc. to Metal	Ore to Metal
- In Slag	4.2	3.0	4.2	2.1	4.3	2.1	4.2	2.1	1.9	1.0
- In Matte to O.D.	2.0	1.4	2.4	1.2	2.4	1.2	2.4	1.2	1.9	1.0
- In Acid	-	-	-	-	43.3	21.6	72.4	36.2	84.0	42.0
- Emitted to Atmosphere	93.8	67.6	93.4	46.9	50.0	25.0	21.0	10.5	12.2	6.1

TABLE 4 INCO THOMPSON

PRODUCT BREAKDOWN

Basis: 50,000 mty Ni Output

MATERIAL FLOWS (10^3 mty or 10^3 oz/y)	BASE CASE (Existing Process) (No Improved Po Rejection)	OPTIMUM PYRRHOTITE REJECTION			
		Existing Process			RRS Proces
Ore Milled	1,947	2,013			2,003
Nickel/Copper Concentrate	648	367.7			366
Nickel - Electrorefined	44.25	44.15			44.42
- Matte to Ontario Division	5.75	5.85			5.58
Copper - Matte to Ontario Division	3.60	3.67			3.50
Cobalt - Co-Products	0.39	0.47			0.54
- Matte to Ontario Division	0.06	0.06			0.06
Silver - Matte to Ontario Division	270	270			269
PM's - Matte to Ontario Division	11.5	11.5			11.4
SO_2 CAPTURE OPTION	No SO_2 Capture	No SO_2 Capture	SO_2 from Roaster	SO_2 from Roaster & Converters	SO_2 from Roaster
Sulphuric Acid	-	-	159	265.5	306
SO_2 Emissions	313.6	223.8	120	50.4	29.0

TABLE 5 INCO THOMPSON **CAPITAL COSTS**

Basis: 50,000 mty Ni Output

COST ITEM	CDN DOLLARS x 10^3					
	Existing Process				RRS	
	SO_2 from Roaster Only		SO_2 from Roaster and Converters		SO_2 from Roaster only	
Mill (P° Rejection)		6,000		6,000		6,000
Smelter						
- Roaster Replacement or Modification	-		-		10,899	
- Electric Furnace Modification	-		-		15,929	
- Converter Hoods	-		12,110		-	
- Electrostatic Precipitators	6,168		13,279		11,458	
- Flues	465		1,097		1,025	
- Materials Handling Modification	-		-		10,350	
- Structure	-		-		838	
- Engineering	-		-		6,750	
Sub-Total	6,634		26,486		57,249	
Contingency 27.5%	1,824		7,284		15,743	
Total for Smelter	8,458	8,458	33,770	33,770	72,993	72,993
Acid Plant						
- Acid Plant - Battery Limits	14,231		27,428		21,217	
- Acid Storage & Loading	11,075		13,041		13,662	
- Services	4,223		9,346		7,317	
- Infrastructure	1,004		1,004		1,004	
- Buildings	2,587		2,587		2,587	
Sub-Total	33,120		53,406		45,787	
Contingency 15%	4,968		8,011		6,868	
Total for Acid Plant	38,088	38,088	61,417	61,417	52,655	52,655
TOTAL FOR MILL, SMELTER & ACID PLANT		**53,046**		**101,687**		**132,148**

TABLE 6 INCO THOMPSON **INCREMENTAL OPERATING COSTS FOR MODERNIZATION OPTIONS**

Basis: 50,000 mty Ni Output

PLANT AREA AND COST COMPONENT	1980 CDN $/Y			
	Optimum Pyrrhotite Rejection			
	Existing Process			RRS Process
	No SO_2 Capture	SO_2 from Roaster Only	SO_2 from Roaster & Converters	SO_2 from Roaster Only
Mining (1)	+1492	+1492	+1492	+1266
Milling	+422	+422	+422	+358
Smelter:				
- Operating Labour	-1027			-225
- Materials & Supplies	-1445			- 10
- Maintenance Labour & Supplies	0			- 764
- Energy	-2462			+1802
TOTAL SMELTING	-4934	-4934	-4934	+803
Acid Plant	0	+2000	+4000	+3800
TOTAL INCREMENTAL OPERATING COSTS	-3020	-1020	+980	+6227

(1) Does not include preproduction costs (exploration, mine development etc.)

TABLE 7 INCO THOMPSON

INCREMENTAL THROUGHPUTS AND REVENUES

For Modernization Options

Basis: 50,000 mty Ni Output

	OPTIMUM PYRRHOTITE REJECTION					
	Existing Process				RRS Process	
	10^3 mty or 10^3 oz/y		10^6 $C/y		10^3 mty or 10^3 oz/y	10^6 $C/y
Nickel ($US 2^{90}/lb)	0		0		0	0
Copper ($US 0.64/lb)	+0.07		+0.12		-0.10	-0.18
Cobalt ($US 4.50/lb)	+0.08		+0.99		+0.15	+1.87
Silver ($US 10^{50}/oz)	0		0		-1.0	-0.01
PM'S ($US 305/oz)	0		0		-0.1	-0.04
Total Metals	-		+1.11		-	+1.54
SO_2 CAPTURE OPTION	Roaster Only	Roaster & Converter	Roaster Only	Roaster & Converter	Roaster Only	
H_2SO_4 (-$US 40/mt)	+159	+265.5	-7.95	-13.25	+306	-15.30
TOTALS	-	-	-6.84	-12.14	-	-13.76

$US = 1.25 $C

TABLE 8 INCO THOMPSON
BASIS: 50,000 tpy Ni

MODERNIZATION OPTIONS
SUMMARY TABLE

Incremental Throughputs Revenues and Costs	Optimum Pyrrhotite Rejection			
	Existing Process		RRS Process	
	Outputs	10^6 $C/Y	Outputs	10^6 $C/Y
Ore Milled (10^3 mty)	+66	-	+56	-
Nickel Products (10^3 lb/y)	0	0	0	0
Copper Products (10^3 lb/y)	+154	+0.12	-220	-0.18
Cobalt Products (10^3 lb/y)	+176	+0.99	+330	+1.87
Silver (10^3 oz/y)	0	0	-1.0	-0.01
PM's (Pt + Au) (10^3 oz/y)	0	0	-0.1	-0.04
TOTAL		+1.11		+1.54

SO_2 Capture Option	No SO_2 Capture	Roasters Only	Roasters & Converters	Roasters Only
H_2SO_4 (10^3 mty)	0	+159	+265	+306
(10^6 $c/y)	0	-7.95	-13.25	-15.3
Incremental Revenues (10^6 $c/y)	+1.11	-6.84	-12.14	-13.76
Incremental Operating Costs (10^6 $c/y)	-3.02	-1.02	+ 0.98	+ 6.23
Total Incremental Surplus (10^6 $c/y)	+4.13	-5.82	-13.12	-19.99
Capital Costs (10^6 $c)	6	53	101	132
SO_2 Emissions Incremental	-90 (-29%)	-194 (-62%)	-263 (-84%)	-285 (-91%)
(10^3 mty) Actual	224	120	50	29